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Contamination control in EUV exposure tools

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June 12, 2013

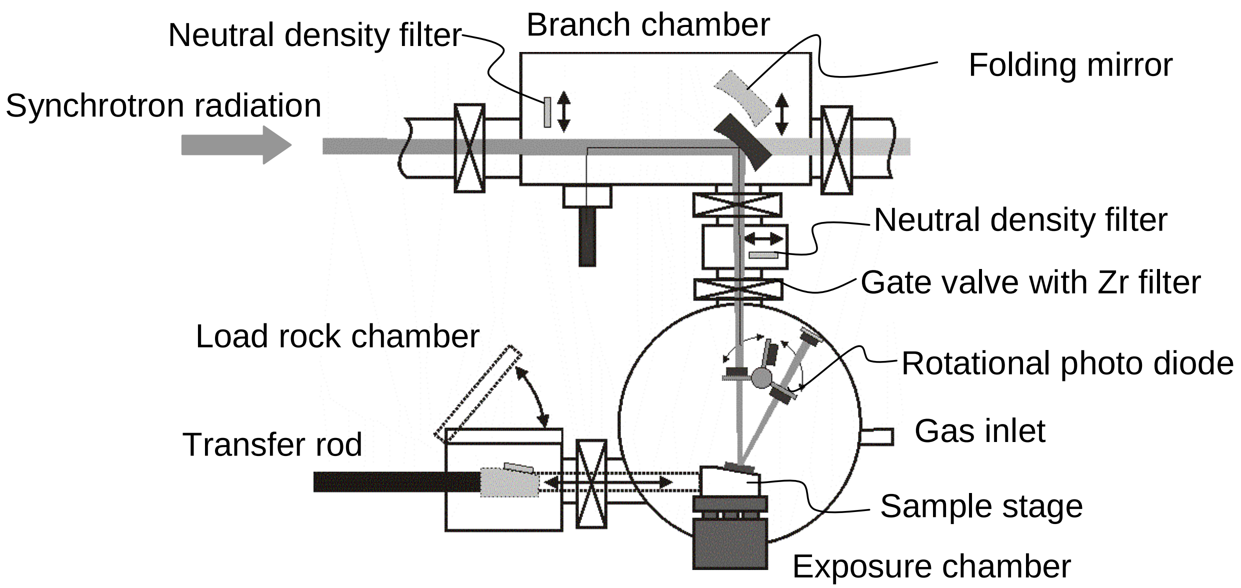
Contamination control in EUV exposure tools

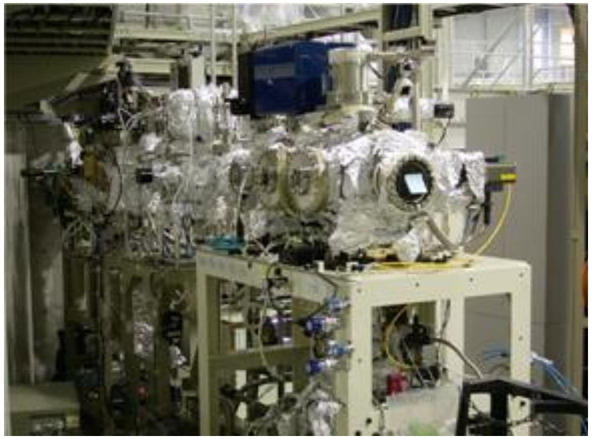
- **EUV-induced contamination**
  - **Carbon contamination**
  - **Surface oxidation**
- **Particles in vacuum**

Contamination control in EUV exposure tools

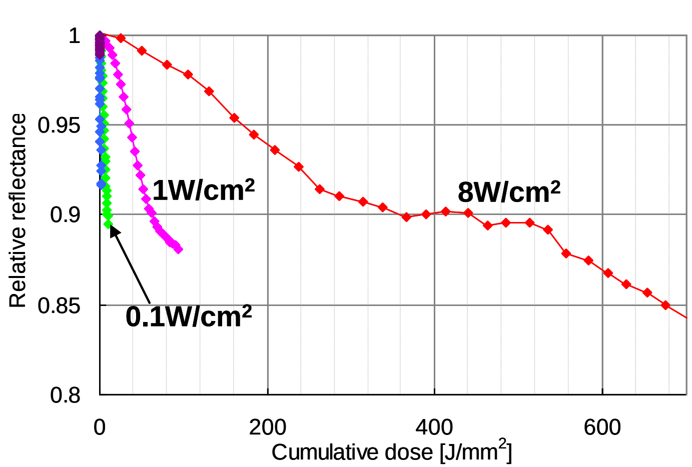
- **EUV-induced contamination**
  - **Carbon contamination**
    - ✓ **EUV + O_2 mitigation**
    - ✓ **On-body UV dry cleaning**
  - **Surface oxidation**
- **Particles in vacuum**

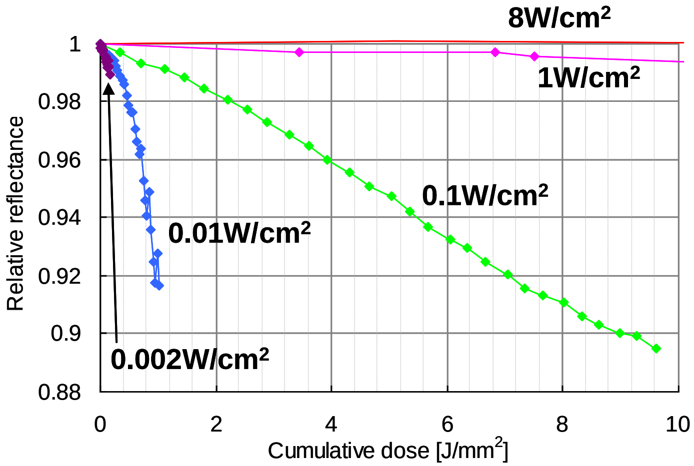
Contamination study using a synchrotron facility





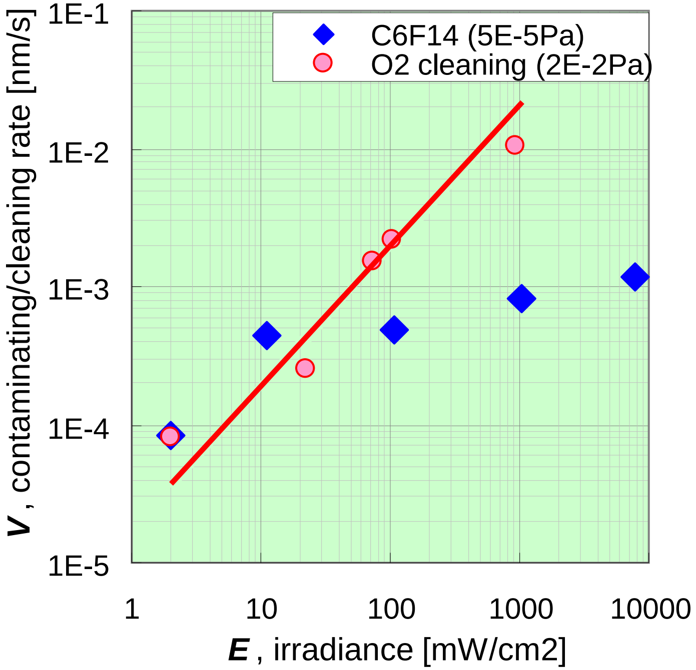
BL 18 at SAGA LS SR facility



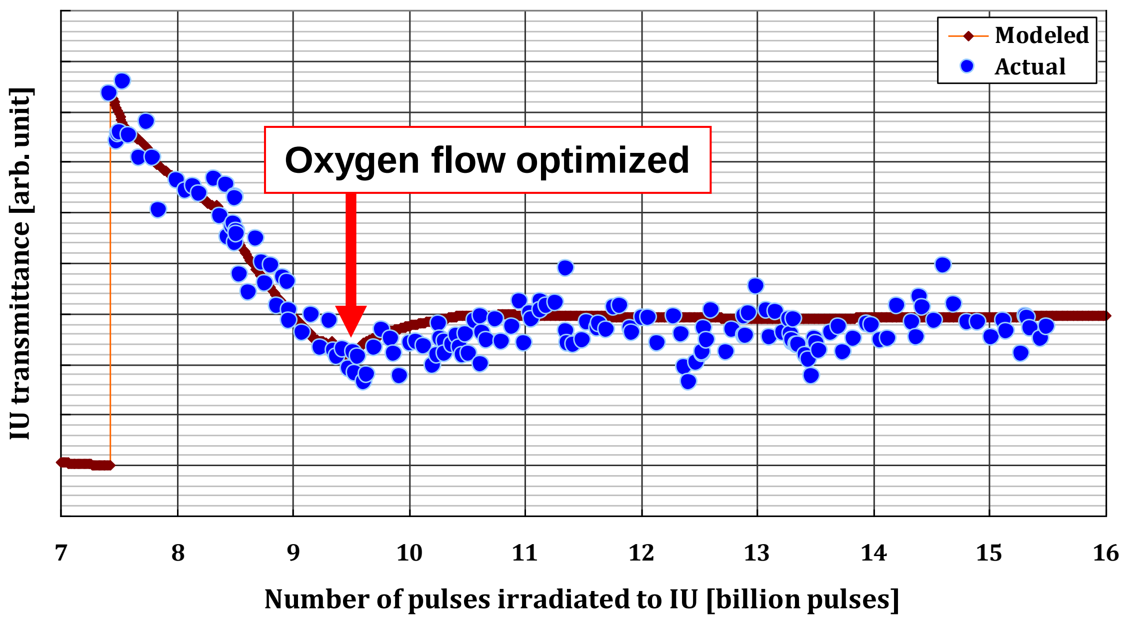


Contamination growth with perfluorohexane (C_6F_{14})

EUV + O_2 mitigation of carbon contamination



Contamination growth rate and O_2 cleaning rate



History of IU transmittance of EUV1

O_2 cleaning rate exceeds carbon contamination growth rate in appropriate condition. Degradation of IU (Illumination Unit) transmittance of EUV1 was stopped after optimization of O_2 flow rate.

EUV + O_2 mitigation is very effective to carbon contamination.

UV dry cleaning of carbon contamination

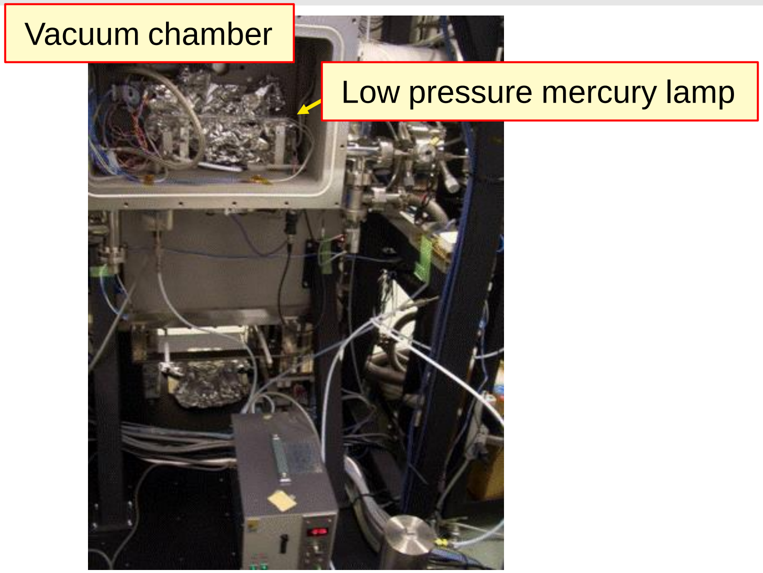
UV dry cleaner using a low pressure mercury lamp

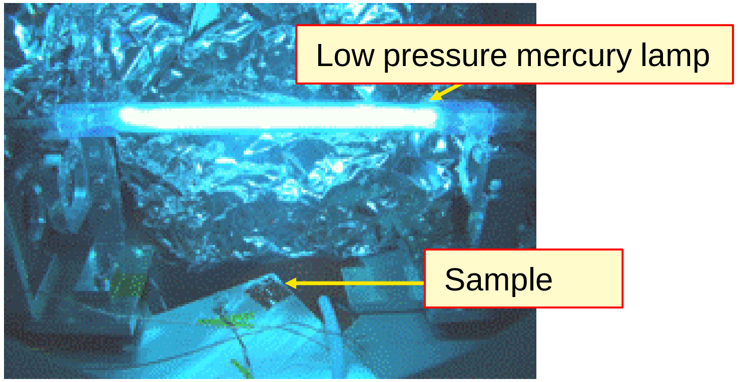
Before cleaning

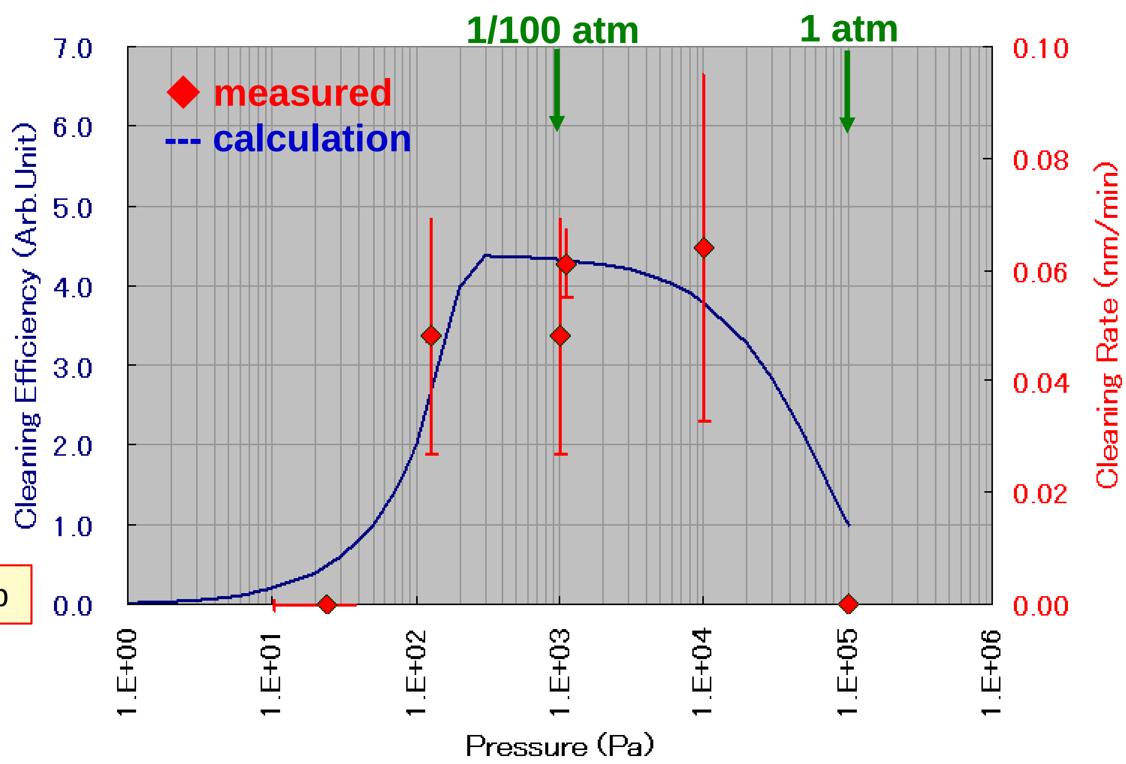
After cleaning

Carbon contamination on a illumination optics of EUV1 can be removed with UV dry cleaning. Initial reflectivity was recovered.

UV dry cleaning in depressurized atmosphere



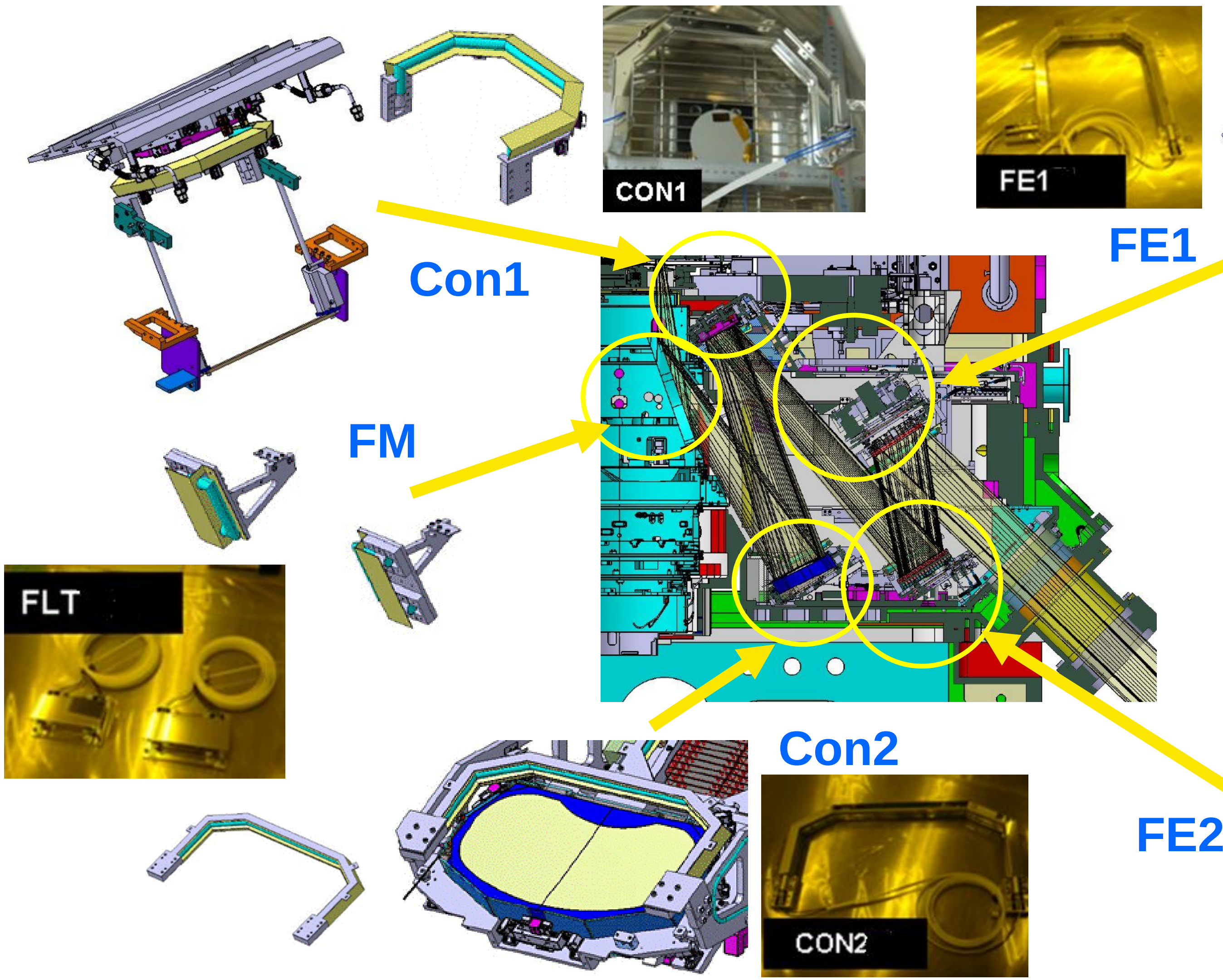


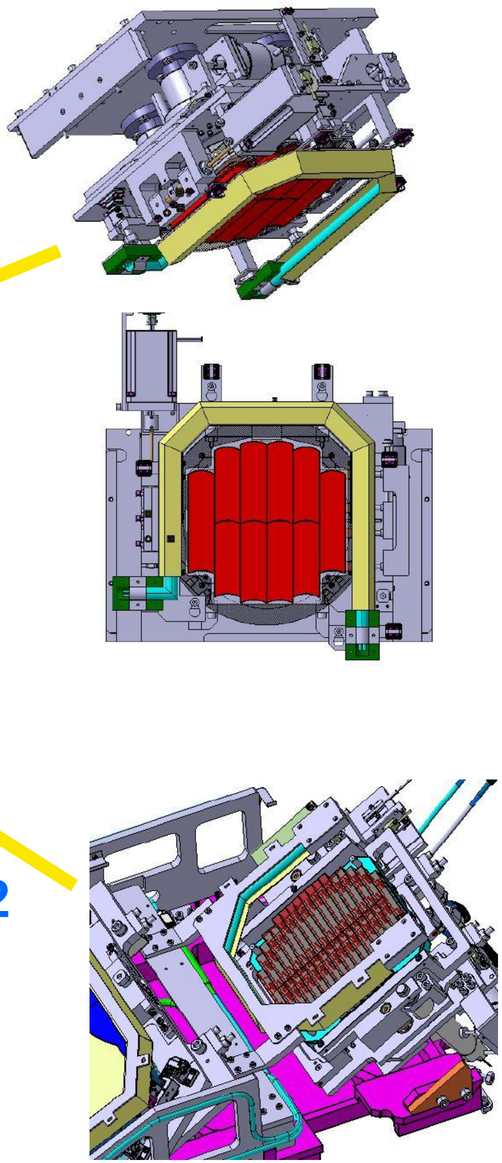


Cleaning rate of carbon contamination with UV dry cleaning increases with reduced pressure.

UV dry cleaning was applied to an on-body cleaning method in EUV1.

On-body UV dry cleaning for IU of EUV1



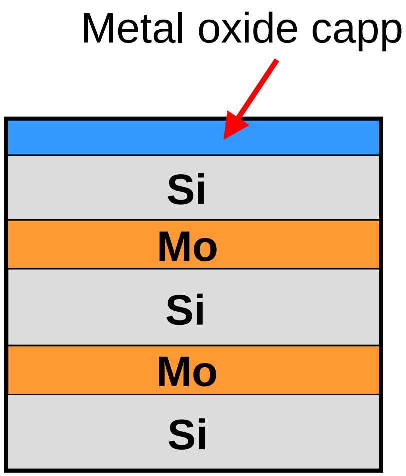


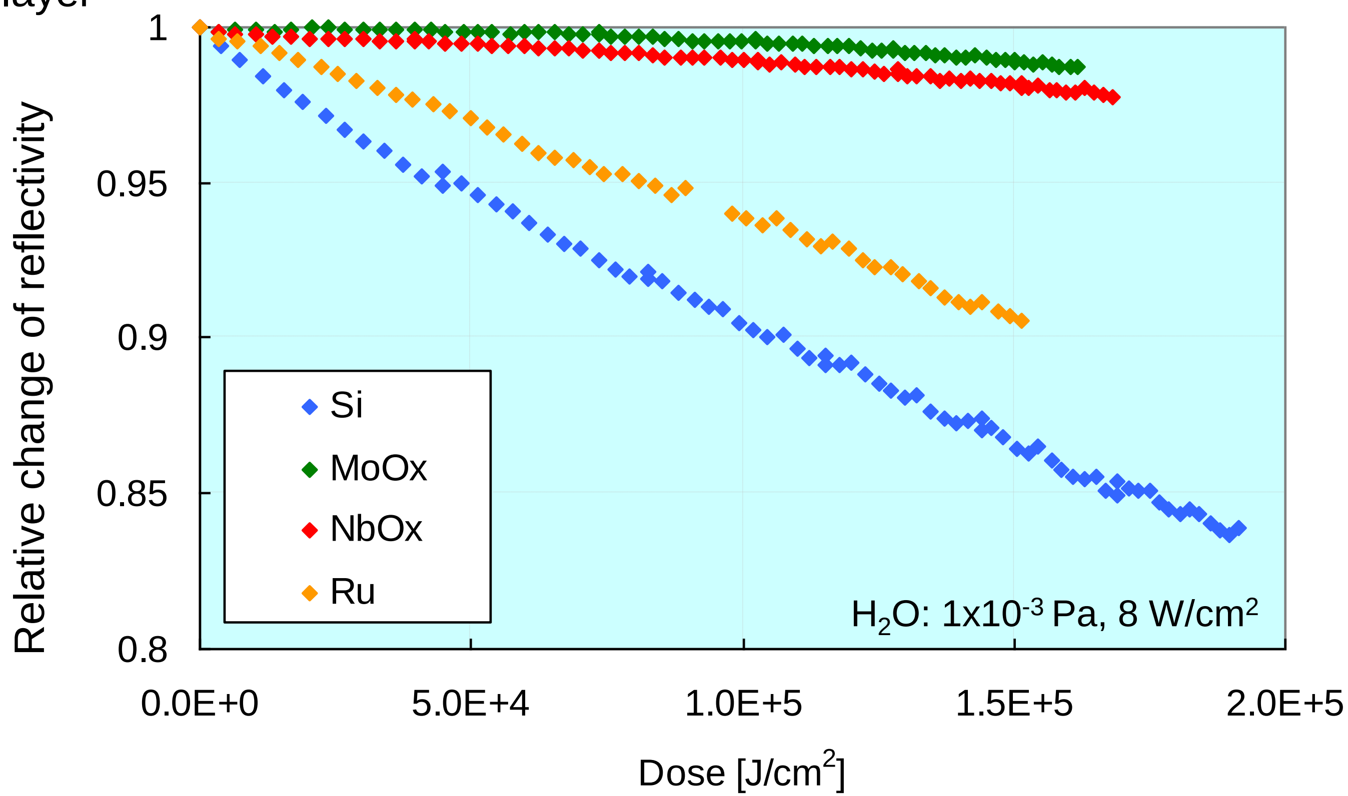
Low pressure mercury lamps placed near each mirror enabled on-body cleaning of illumination optics.

Contamination control in EUV exposure tools

- **EUV-induced contamination**
  - **Carbon contamination**
    - ✓ EUV + O_2 mitigation
    - ✓ On-body UV dry cleaning
  - **Surface oxidation**
    - ✓ Metal-oxide capping layer
- **Particles in vacuum**

Metal oxide capping layer





Reflectivity change of Mo/Si multilayers with several different capping layer materials during EUV exposure in water vapor was measured.

Metal oxide capping layers have much higher oxidation durability compared with conventional Ru capping layer.

Contamination control in EUV exposure tools

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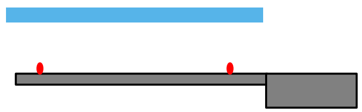
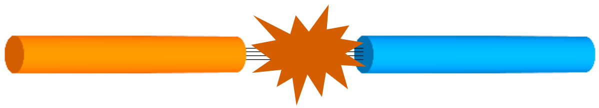
  - **Surface oxidation**
    - ✓ **Metal-oxide capping layer**
- **Particles in vacuum**
  - ✓ **Particle capture using silica aerogel**

Particles in vacuum: Materials

- **Potential particle generating events**
  - **Physical contact**



    - Collisions: wafer/reticle transfer, pod open/close, valve o/c, grounding pin contact, …
    - Rubbing: bearings, ultrasonic motors, …
  - **Physical reaction**
    - Sputtering: corona ionizers, EUV sources, …
    - Evaporation and condensation: pumping down in load lock
  - **Electrical discharge/spark**



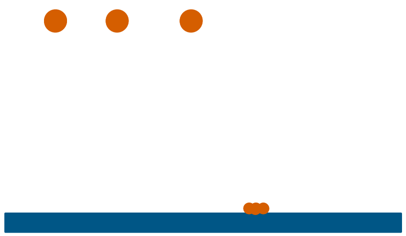
    - EUV sources
    - Discharge between reticle and pod during a transitional region in load lock
    - Micro-discharge between wafer/reticle backsides and e-chucks.
- **Potential materials**
  - Metal/metalloid: Na, Al, Si, K, Ca, Ti, Cr, Fe, Ni, Mo, Ru, Sn, Ta, …
  - Inorganic: SiO_2, …
  - Organic: $C_xH_yO_z$

HEAVY! > 7 g/cm^3

cf. PSL~1 g/cm^3

Particle in vacuum: Velocities

- Interaction with surfaces "bounce or stick" depends on the relationship between the particle impact velocity v_i and the critical velocity v_c.
  - $v_i < v_c$: stick
  - $v_i > v_c$: bounce
  - $v_i >> v_c$: split and stick/bounce

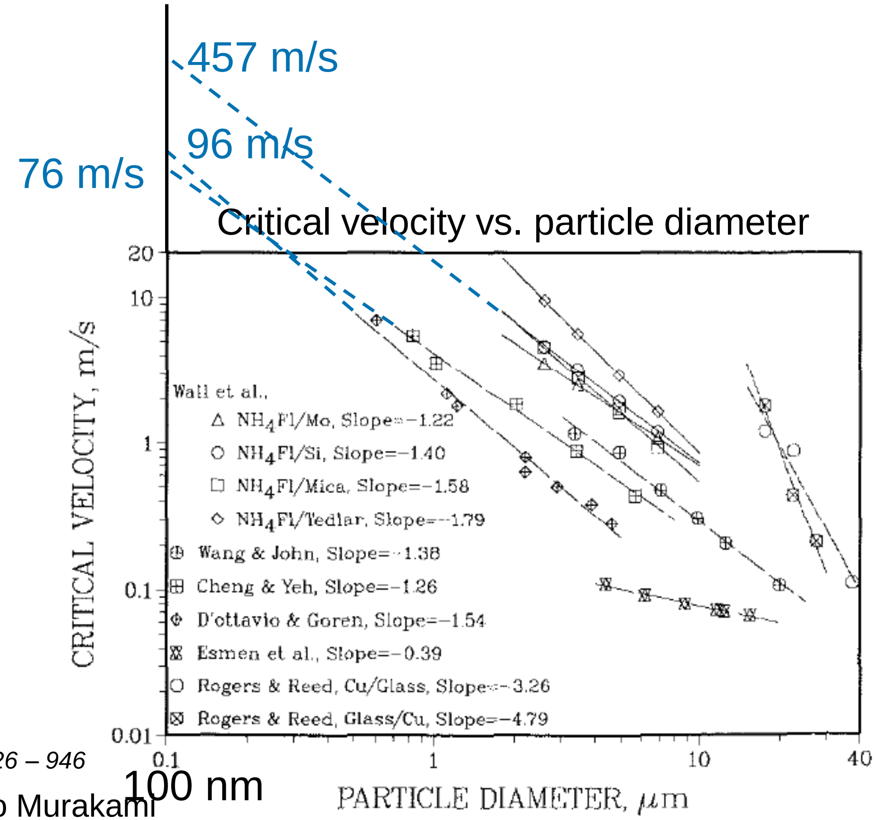


¥ v_c is determined by the surface material, the particle material, the particle size, etc.

- Particles that have lower velocities than the critical velocity cannot continue to fly.

FAST!

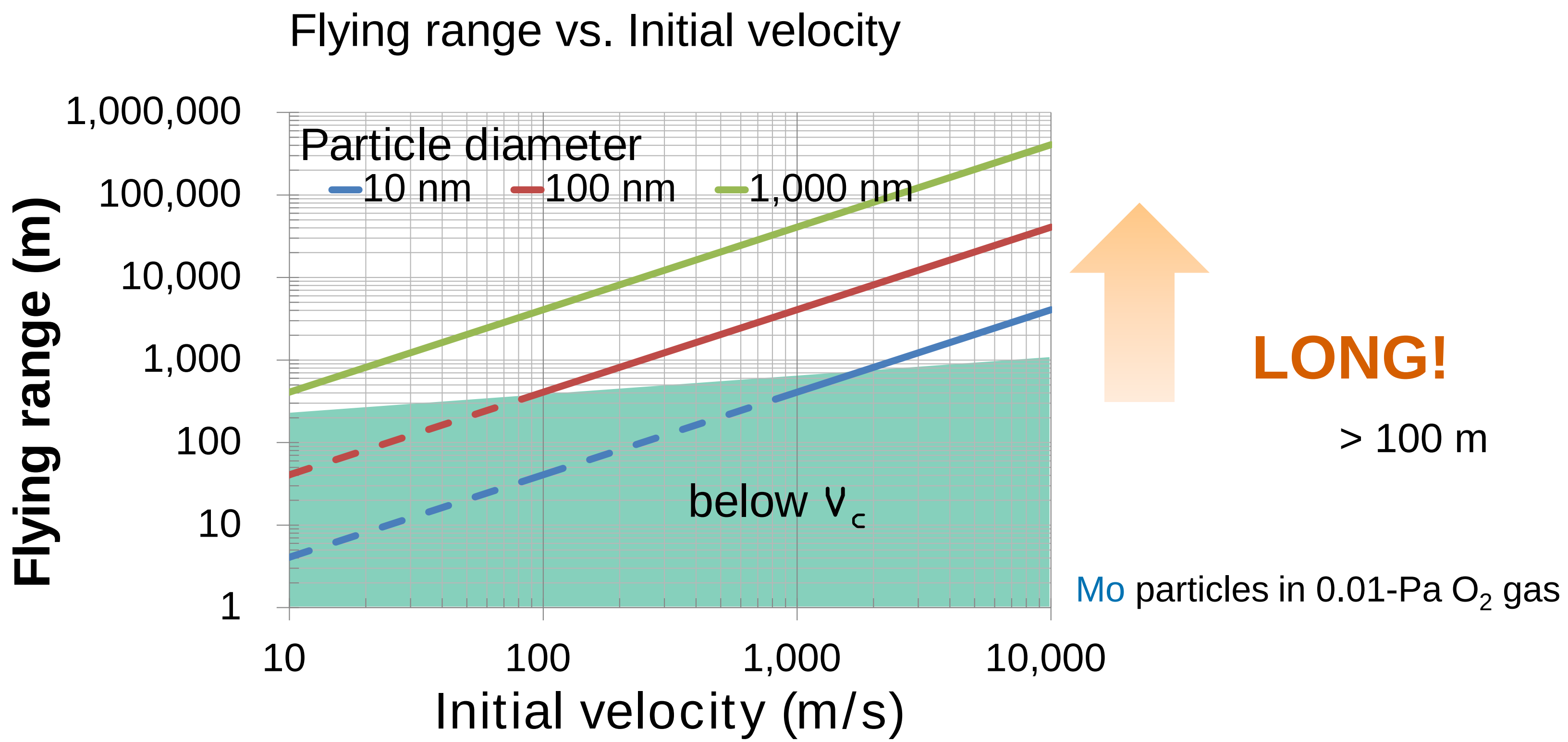
Typical v_c :
100 m/s for 100-nm particles
2,000 m/s for 10-nm particles



S. Wall, et al., Aerosol Science and Technology, Volume 12, Issue 4, 1990, Pages 926 – 946

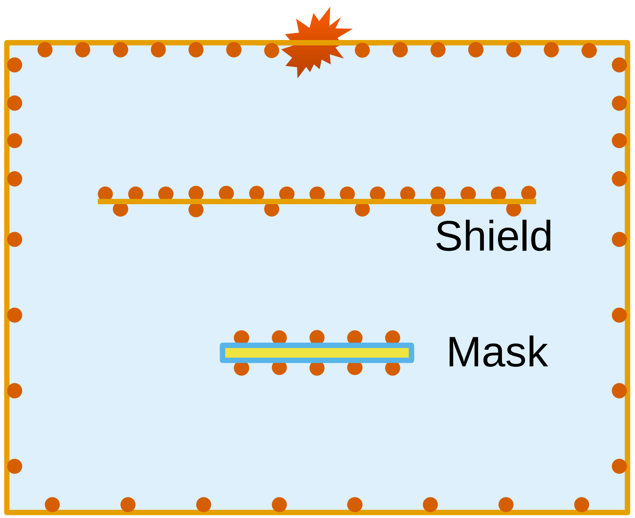
Particles in vacuum: Flying range

- Forces acting on particles in vacuum
  - **Gravity**: $\propto r^3$, dominant force but not decelerating force
  - **Drag force**: $\propto r^2$, weak, depends on the gas pressure
  - Coulomb force: weak, depends on E and amount of electric charge
  - Thermophoretic force: very weak, depends on the thermal gradient



Particle reduction system

Particle shield



Particle source at the top.
Shield between the particle source and the mask.

→ **Performance of shield is insufficient.**

Particle source at the top.
Particle catcher on the shield.

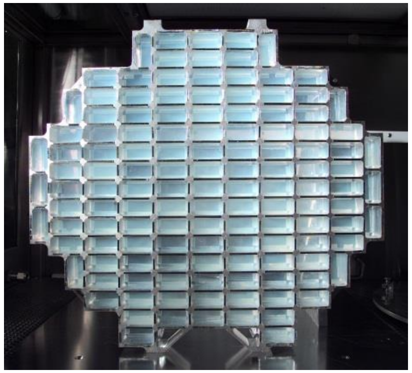
→ **Particle catcher can drastically reduce the number of flying particles.**

To simplify the models, gravity is neglected and the same coefficient of restitution (COR) is used for both the vertical component and the parallel component to the wall.

Silica aerogel as particle catcher

STARDUST : NASA's comet sample return mission, 1999 - 2011

February 7, 1999
Stardust Launch



Dust Collector with aerogel

Comet particles

Velocity: ~ 6.5 km/s
Diameter: 40 - 300 µm

Vacuum tool particles

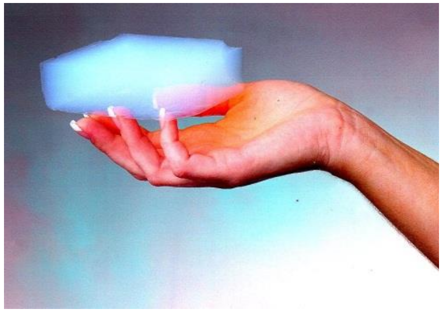
Velocity: 10 m/s - 1 km/s
Diameter: 1 µm - 10 nm

1

Kinetic energy

$10^{-13\ -\ -15}$

Thinner sheet is enough for EUV tools.



Aerogel In Hand

Photos from jpl.nasa.gov

Particle Tracks in Aerogel (experiment)

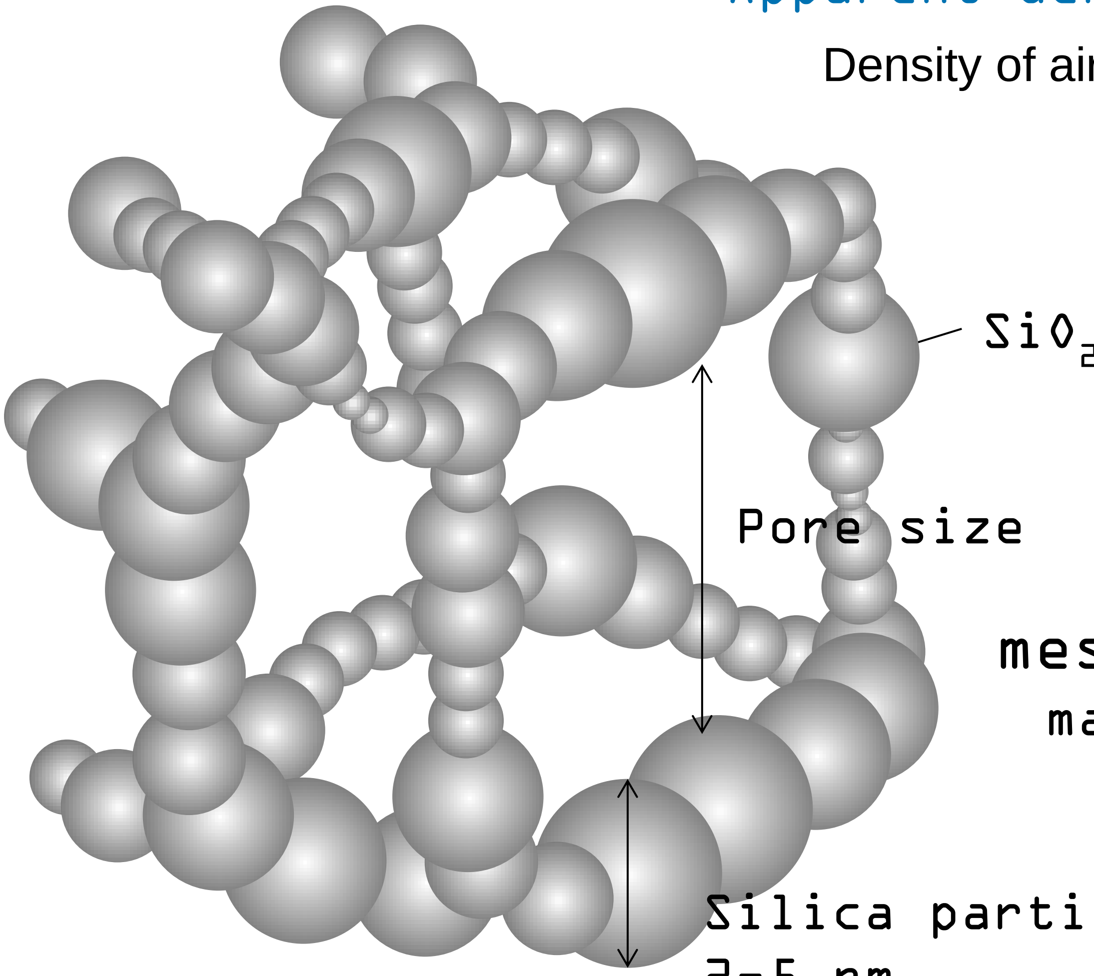
Comet Ejecta in Aerogel

Structure of silica aerogels

Pore network

Apparent density: 0.003-0.35 g/cm

Density of air: 0.0012 g/cm^3 at 20 ° C



micro pores: < 2 nm

mesopores: 2-50 nm

macro pores: > 50 nm

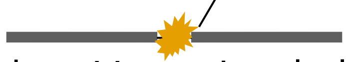
Experimental setup of particle catcher

MPE Tool

Particle generator installed in ESC chamber

High voltage feedthroughs

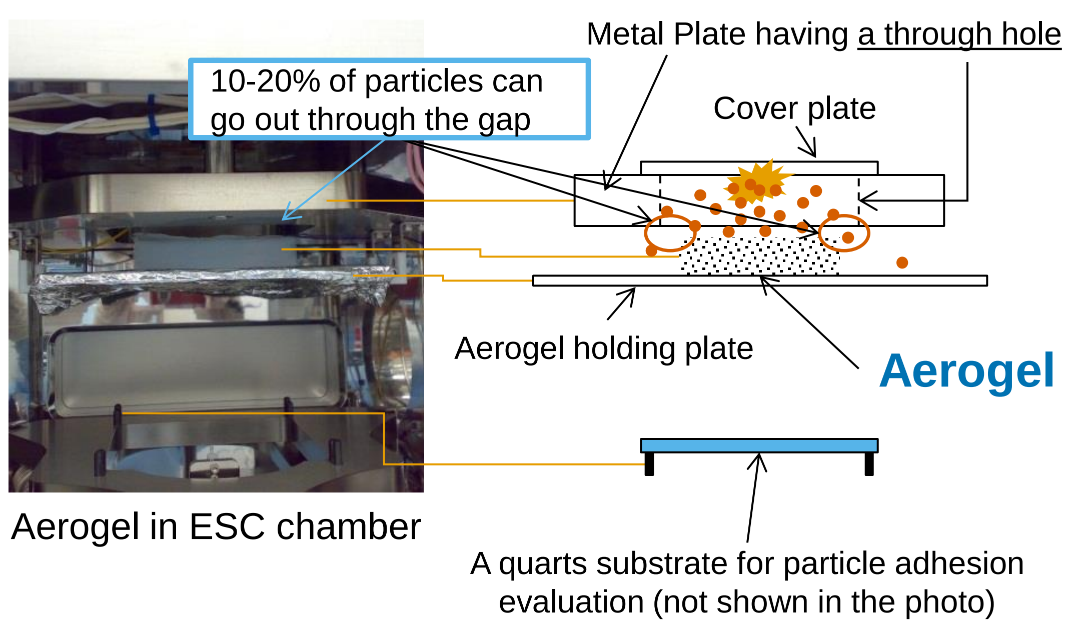
Induction coil



Particles were generated by discharging
(Air pressure ~5E-3 Pa)

Photos of aerogel tested:
bare (left) and covered by a foil (right)

Size: 100 mm (W), 100 mm (D), 15 mm (H)
Density: 0.012 g/cm^3



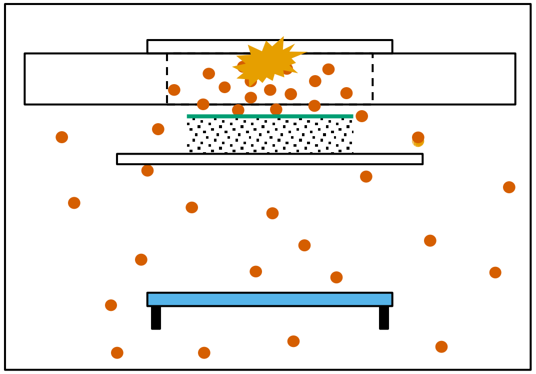
Aerogel in ESC chamber

Experimental conditions of particle catcher

#1: Aerogel sheet covered with a foil

- An aerogel sheet covered by a foil on the holding plate was put between the quarts substrate and the particle generator.
- Discharging was continuously and the total time was about 8 seconds.

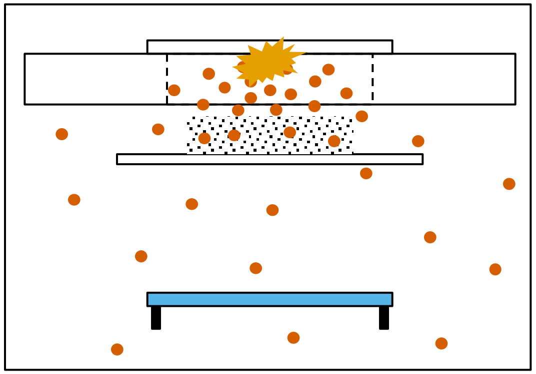
Particles are not captured.



#2: Bare aerogel sheet

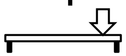
- The foil was removed.
- Discharging was continuously and the total time was about 8 seconds.

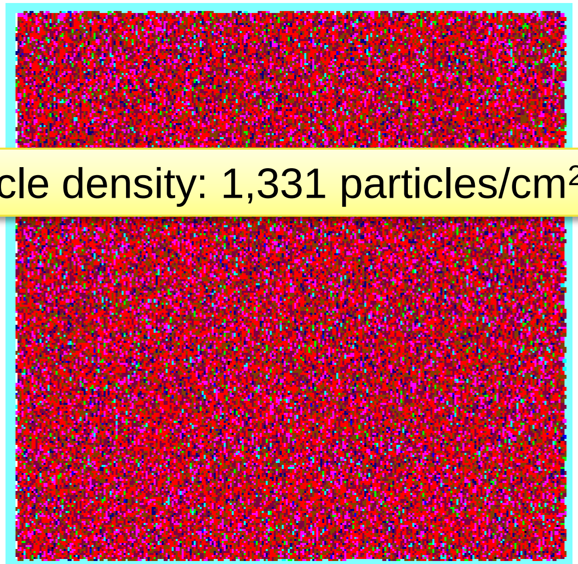
Particles are captured.



Experimental results #1: Covered with foil

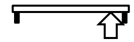
Up

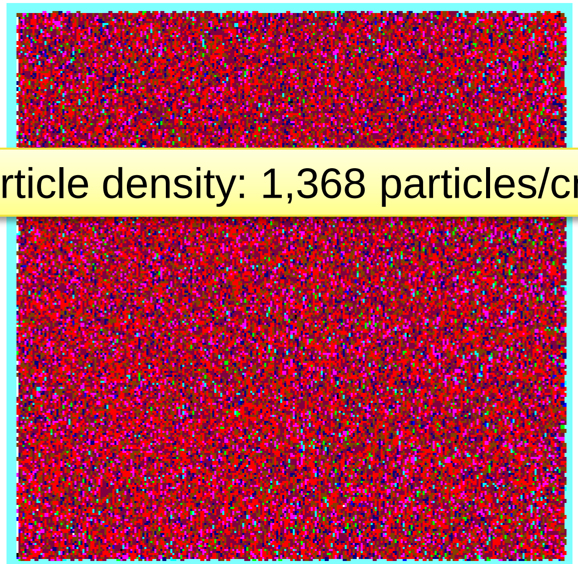




Particle density: 1,331 particles/cm^2

Down

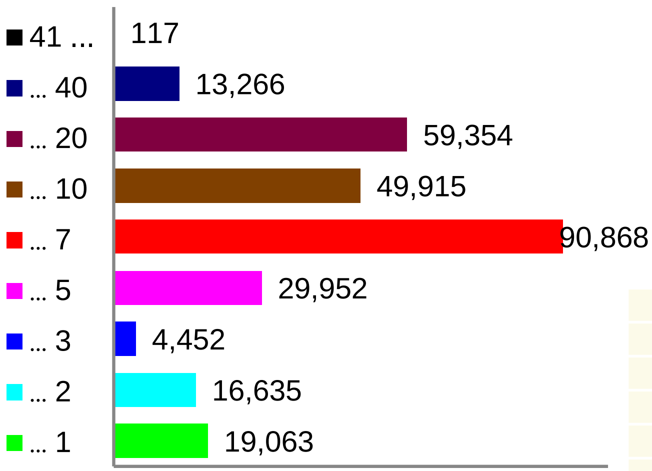




Particle density: 1,368 particles/cm^2

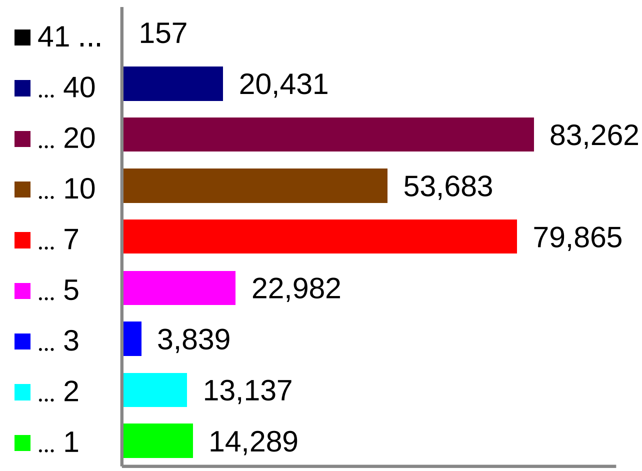
Almost the same density

Pixel Histogram



Total = 283,622

Pixel Histogram

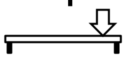


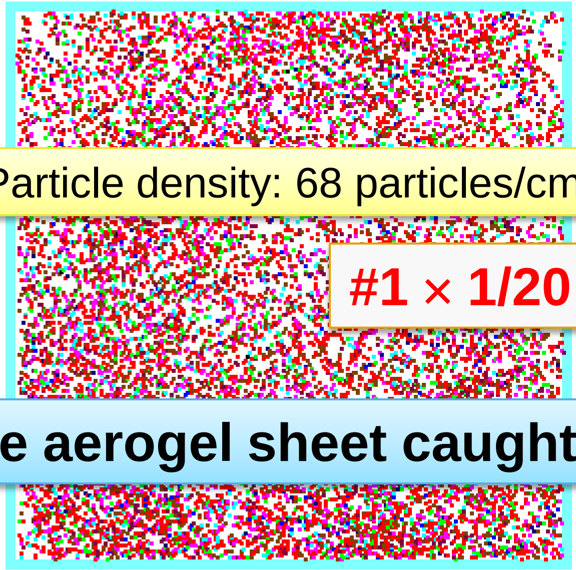
Total = 291,645

26-	>=300 nm
22-25	200 nm
17-21	100 nm
14-16	80 nm
11-13	70 nm
7-10	60 nm
1-6 pix	=< 50 nm

Experimental results #2: Bare aerogel

Up

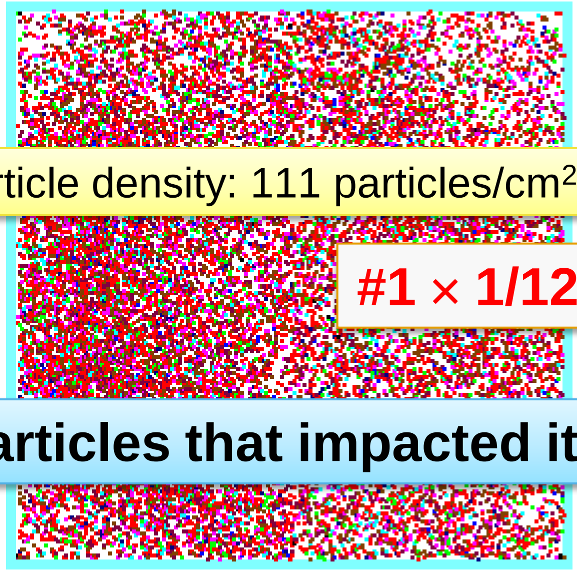




Particle density: 68 particles/cm^2

#1 × 1/20

Down

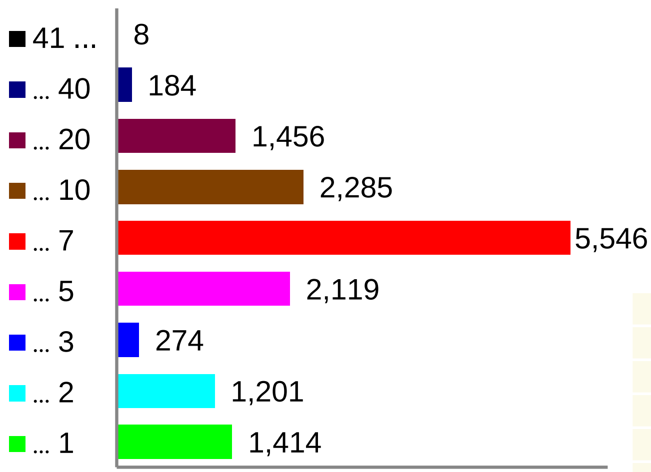


Particle density: 111 particles/cm^2

#1 × 1/12

The aerogel sheet caught almost all particles that impacted it !!

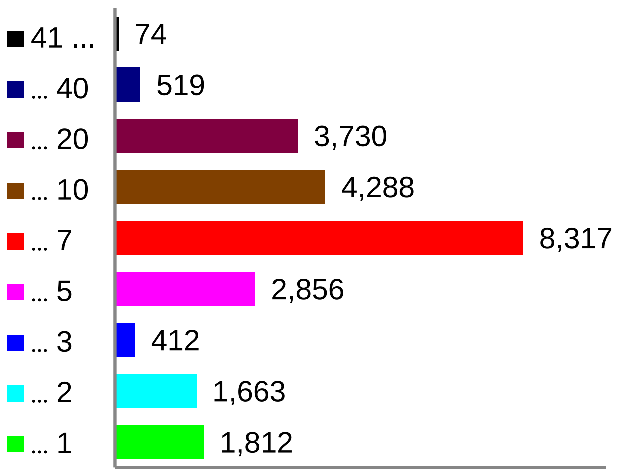
Pixel Histogram



Total = 14,487

26-	>=300 nm
22-25	200 nm
17-21	100 nm
14-16	80 nm
11-13	70 nm
7-10	60 nm
1-6 pix	=< 50 nm

Pixel Histogram



Total = 23,671

Summary

- Oxygen introduction during EUV exposure effectively mitigates carbon contamination growth on optical elements in EUV exposure tools.
- Carbon contamination on optical elements can be removed by UV dry cleaning. It can be applied to an on-body cleaning method in EUV exposure tools.
- Surface oxidation of multilayer mirrors during EUV exposure can be prevented by using metal-oxide capping layer.
- Particles in a vacuum chamber fly very long distance. Silica aerogel is suitable material to capture such flying particles in EUV exposure tools.

Acknowledgements

- EUVA
- NEDO
- METI
- Selete & EIDEC
- SAGA Light Source
- Chiba University
- Panasonic Corp.

Thank you for your attention.

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